Chapter 4. Sediment Characteristics

INTRODUCTION

Ocean sediment samples are collected and analyzed as part of the Point Loma Ocean Outfall (PLOO) monitoring program to characterize the surrounding physical environment and assess general sediment conditions. These conditions define the primary microhabitats for benthic invertebrates that live within or on the surface of sediments, and can therefore influence the distribution and presence of various species. The distributions of many demersal fishes are also often associated with specific sediment types that reflect the habitats of their preferred invertebrate prey (Cross and Allen 1993). Consequently, an understanding of differences in sediment conditions over time and space is crucial to assessing coincident changes in benthic invertebrate and demersal fish populations (see Chapters 5 and 6, respectively).

Both natural and anthropogenic factors affect the composition, distribution, and stability of seafloor sediments. Natural factors that affect sediment conditions on the continental shelf include the strength and direction of bottom currents, exposure to wave action, seafloor topography, inputs associated with outflows from rivers and bays, beach erosion, runoff from other terrestrial sources, bioturbation by benthic macrofauna, and decomposition of calcareous organisms (e.g., Emery 1960). The analysis of parameters such as sediment grain size and the relative percentages of different sediment fractions (e.g., sand, silt, and clay) can provide useful information about current velocity, amount of wave action and overall habitat stability in an area. Further, understanding sediment particle size distributions facilitates interpretation of the interactions between benthic organisms and the environment. For example, differences in sediment composition (e.g., fine vs. coarse particles) and associated levels of organic loading at specific sites can affect the burrowing, tube building, and feeding abilities of infaunal invertebrates, thus affecting benthic community structure (Gray 1981, Snelgrove and Butman 1994). Geological history can also affect the chemical composition of local sediments. For example, erosion from coastal cliffs and shores, and flushing of terrestrial sediments and debris from bays, rivers, and streams can contribute to the deposition and accumulation of metals or other contaminants and also affect the overall organic content of sediments. Additionally, primary productivity by phytoplankton is a major source of organics to these sediments (Mann 1982, Parsons et al. 1990). Finally, particle size composition can affect concentrations of chemical constituents within sediments. For example, levels of organic compounds and trace metals within ocean sediments generally rise with increasing amounts of fine particles (Emery 1960, Eganhouse and Venkatesan 1993).

Municipal wastewater outfalls are one of many anthropogenic factors that can directly influence the composition and distribution of sediments through the discharge of treated effluent and the subsequent deposition of a wide variety of organic and inorganic compounds. Some of the most commonly detected compounds discharged via ocean outfalls are trace metals, pesticides, and various organic compounds such as organic carbon, nitrogen, and sulfides (Anderson et al. 1993). Moreover, the presence of large outfall pipes and associated ballast materials (e.g., rock, sand) may alter the hydrodynamic regime in surrounding areas.

This chapter presents summaries and analyses of sediment grain size and chemistry data collected during 2009 at monitoring sites surrounding the PLOO. The primary goals are to: (1) assess possible effects of wastewater discharge on benthic habitats by analyzing spatial and temporal variability of various sediment parameters, (2) determine the presence or absence of sedimentary and chemical footprints near the discharge site, and (3) evaluate overall sediment quality in the region.

Materials and Methods

Field Sampling

Sediment samples were collected at 22 benthic stations in the PLOO region during 2009 (Figure 4.1). These stations are located along the 88, 98, and 116-m depth contours, and include "E" stations located within 8 km of the outfall, and "B" stations located greater than 11 km north of the outfall. During 2009, the January survey was limited to 12 "primary core" stations along the 98-m depth contour to accommodate additional sampling for the Bight'08 regional project (see Chapter 1), while the July survey included all 22 stations. The four stations considered to represent "nearfield" conditions herein (i.e., E11, E14, E15, E17) are located between about 100–750 m of the center of the outfall wye or the ends of the diffuser legs. Each sediment sample was collected from one side of a chain-rigged double Van Veen grab with a 0.1-m^2 surface area; the other grab sample from the cast was used for macrofaunal community analysis and visual observations of sediment composition (see Chapter 5). Sub-samples for various analyses were taken from the top 2 cm of the sediment surface and handled according to EPA guidelines (U.S. EPA 1987).

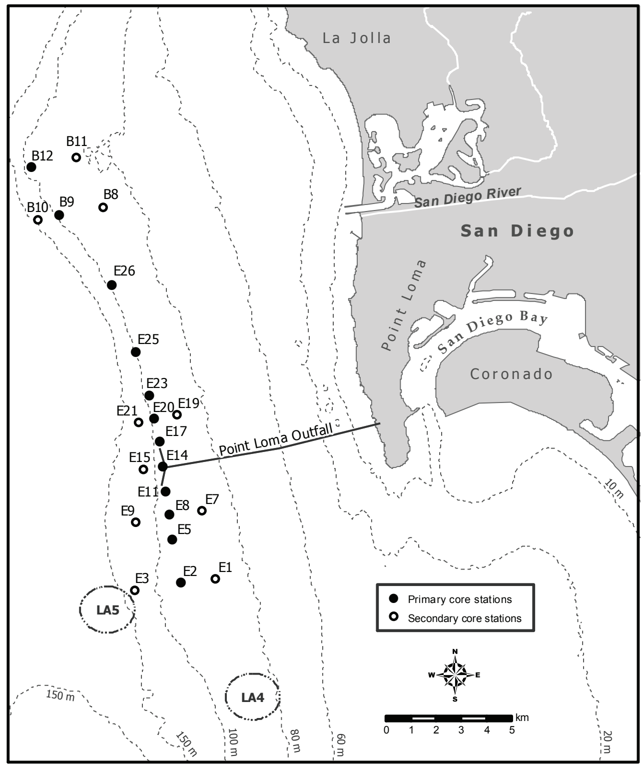

Figure 4.1
Benthic station locations sampled for the Point Loma Ocean Outfall Monitoring Program.

Laboratory Analyses

All sediment chemistry and particle size analyses were performed at the City of San Diego's Wastewater Chemistry Services Laboratory. Particle size analysis was performed using either a Horiba LA-920 laser scattering particle analyzer or a set of six nested sieves. The Horiba analyzer measures particles ranging in size from 0.00049 mm to 2.0 mm (i.e., 11 to -1 phi). Coarser sediments from these samples were removed prior to laser analysis by screening the samples through a 2.0-mm mesh sieve. These data were expressed as "percent coarse" of the total sample sieved, and later combined with the Horiba results to obtain a complete distribution of particle sizes (see below). When a sample contained substantial amounts of coarse materials (e.g., coarse sand, gravel, shell hash) which would damage the Horiba analyzer and/or where the general distribution of sediment sizes would be poorly represented by laser analysis, a set of six nested sieves was instead used to separate the grain size fractions. The mesh sizes of the sieves are 2.0 mm, 1.0 mm, 0.5 mm, 0.25 mm, 0.125 mm, and 0.063 mm, and separate a seventh fraction of all particles finer than 0.063 mm. In 2009, 32 samples were processed by laser analysis and two samples (stations E2 and E14 during July) were processed by sieve analysis. Results from sieve analysis and output from the Horiba were categorized into sand, silt, and clay fractions as follows: sand was defined as particles ranging between 2.0 and >0.0625 mm in diameter, silt as particles between 0.0625 and >0.0039 mm, and clay as particles between 0.0039 and >0.00049 mm. These data were standardized and combined with any sieved coarse fraction (i.e., particles >2.0 mm) to obtain a complete distribution of the coarse, sand, silt, and clay fractions totaling 100%. These four size fractions were then used in the calculation of various particle size parameters, which were determined using a normal probability scale (see Folk 1968). Summaries of particle size parameters included overall mean particle size (mm), phi size (mean, standard deviation, skewness, kurtosis), and the proportion of coarse, sand, silt, and clay. Additionally, the proportion of fine particles (percent fines) was calculated as the sum of all silt and clay fractions for each sample.

Each sediment sample was chemically analyzed to determine concentrations of total organic carbon (TOC), total nitrogen (TN), total sulfides, biochemical oxygen demand (BOD), total volatile solids (TVS), trace metals, chlorinated pesticides (e.g., DDT), polychlorinated biphenyl compounds (PCBs), and polycyclic aromatic hydrocarbons (PAHs) on a dry weight basis (see Appendix C.1). TOC, TN, and TVS were measured as percent weight (% wt) of the sediment sample; BOD, sulfides, and metals were measured in units of mg/kg and are expressed in this report as parts per million (ppm); pesticides and PCBs were measured in units of ng/kg and are expressed as parts per trillion (ppt); PAHs were measured in units of µg/kg and are expressed as parts per billion (ppb). Reported values were generally limited to values above the method detection limit (MDL) for each parameter. However, concentrations below MDLs were included as estimated values if the presence of the specific constituent was verified by mass-spectrometry. A detailed description of the analytical protocols is available in City of San Diego (2010).

Data Analyses

Data summaries for the various sediment parameters measured during 2009 included detection rates, annual means of detected values for all stations combined (areal mean), and minimum, median, and maximum values during the year. Total chlordane, total DDT, total PCB, and total PAH were calculated for each sample as the sum of all constituents with reported values (see Appendix C.2 for individual constituent values). Statistical analyses included Spearman Rank correlation of the percent of fine sediments (% fines) with each chemical parameter. This non-parametric analysis accommodates non-detects (i.e., analyte concentrations measured below the MDL) without the use of value substitutions (Helsel 2005). However, depending on the data distribution, the instability in ranked-based analyses may intensify with increased censoring (see Conover 1980). Therefore, a criterion of < 50% non-detects was used to screen eligible constituents for this analysis. In addition, only parameters analyzed with a single MDL throughout the entire year were considered for correlation analysis (see Helsel 2005). Correlation results were confirmed visually by graphical analyses.

Data from the 2009 surveys were compared to the Effects Range Low (ERL) and Effects Range Median (ERM) sediment quality guidelines of Long et al. (1995) when available to assess contamination levels. The National Status and Trends Program of the National Oceanic and Atmospheric Administration (NOAA) originally established the ERLs and ERMs to provide a means for interpreting environmental monitoring data. The ERLs represent chemical concentrations below which adverse biological effects are rarely observed. Values above the ERL but below the ERM represent values at which effects occasionally occur. Concentrations above the ERM indicate likely biological effects, although these are not always validated by toxicity testing (Schiff and Gossett 1998). Contamination levels were further evaluated by comparing results for the current year with historical data, including comparisons between the maximum values for 2009 to those from the pre-discharge period (i.e., 1991–1993). In addition, data for percent fines and organic indicators from the nearfield stations were compared to data from the northern reference stations, as well as stations between 1–8 km to the north and south of the outfall, over the pre-and post-discharge periods.

Results and Discussion

Particle Size Distribution

During 2009, ocean sediments collected off Point Loma were composed predominantly of coarse silt and very fine sands, with mean particle sizes ranging from about 0.04 to 0.12 mm (Table 4.1).

Table 4.1

Summary of particle size and sediment chemistry parameters at PLOO benthic stations during 2009. Data include the detection rate (DR), areal mean of detected values, and minimum (Min), median, and maximum (Max) values for the entire survey area. The maximum value from the pre-discharge period (i.e., 1991–1993) is also presented. ERL=effects range low threshold; ERM=effects range median threshold; na=not available; nd=not detected; SD=standard deviation; BOD=biochemical oxygen demand; TN=total nitrogen; TOC=total organic carbon; TVS=total volatile solids.

	2009 Summary*					Pre-discharge		
Parameter	**DR (%)**	**Areal Mean**	**Min**	**Median**	**Max**	**Max**	**ERL**	**ERM**
Particle Size								
Mean (mm)	**	0.06	0.04	0.06	0.12	0.18	na	na
Mean (phi)	**	4.1	3.1	4.1	4.6	5.8	na	na
SD (phi)	**	1.5	0.7	1.5	1.9	3.0	na	na
Coarse (%)	**	0.8	0.0	0.0	9.3	26.4	na	na
Sand (%)	**	61.2	43.2	62.2	72.1	79.3	na	na
Fines (%)	**	38.0	27.9	37.2	56.8	74.2	na	na
Organic Indicators								
BOD (% weight)	97	270	nd	238	>535	656	na	na
Sulfides (ppm)***	97	3.35	nd	1.35	33.90	20.00	na	na
TN (% weight)	100	0.051	0.030	0.051	0.087	0.074	na	na
TOC (% weight)	100	1.02	0.46	0.69	4.27	1.57	na	na
TVS (% weight)	100	2.45	1.67	2.25	5.42	5.00	na	na
Trace Metals (ppm)								
Aluminum	100	7504	3130	7660	11,300	na	na	na
Antimony	12	0.4	nd	nd	0.4	6.0	na	na
Arsenic	100	3.14	1.49	2.78	7.27	5.56	8.2	70
Barium	100	35.3	10.3	33.8	58.8	na	na	na
Beryllium	65	0.23	nd	0.19	0.34	2.01	na	na
Cadmium	94	0.13	nd	0.12	0.18	6.80	1.2	9.6
Chromium	100	15.9	7.4	15.7	23.6	51.0	81	370
Copper	100	6.5	1.5	6.2	11.7	34.0	34	270
Iron	100	11,869	5570	11,300	17,900	26,000	na	na
Lead	100	4.5	2.1	4.0	13.2	18.0	46.7	218
Manganese	100	83.3	35.9	85.8	114.0	na	na	na
Mercury	100	0.028	0.009	0.024	0.065	0.096	0.15	0.71
Nickel	100	6.8	3.1	6.8	9.1	14.0	20.9	51.6
Selenium	6	0.25	nd	nd	0.25	0.90	na	na
Silver	0	—	nd	nd	nd	7.00	1	3.7
Thallium	0	—	nd	nd	nd	152.0	na	na
Tin	91	0.8	nd	0.9	1.3	na	na	na
Zinc	100	29.4	14.3	28.7	47.8	67.0	150	410
Pesticides (ppt)								
Chlordane	6	650	nd	nd	950	nd	na	na
tDDT	71	507	nd	335	1120	8800	1580	46,100
Endrin aldehyde	3	970	nd	nd	970	nd	na	na
HCB	32	377	nd	nd	1600	nd	na	na
Total PCB (ppt)	50	3126	nd	nd	22,315	na	na	na
Total PAH (ppb)	9	174	nd	nd	312	199	4022	44,792

* Minimum, maximum, and median values were calculated based on all samples (n=34), whereas means were calculated on detected values only ($n \leq 34$).

** Particle size parameters calculated for all samples.

*** Sulfide samples for stations B9 and B12 in the January survey held over time limit; results not reportable.

There was little difference in intra-station particle size composition between the January and July surveys. The greatest difference occurred at station E2, where percent fines varied from 43% in January to 35% in July, with the average particle size increasing by about 0.06 mm (Appendix C.3). Overall, percent fines averaged 38% across the region during the year, ranging from a low of 28% to a high of 57% (Figure 4.2). No major changes in percent fines composition of PLOO sediments have occurred since the initiation of wastewater discharge at the end of 1993 (Figure 4.3). However, there has been a slight decrease in percent fines and a corresponding increase in mean particle size at station E14 located nearest the discharge site (see City of San Diego 2007). This increase may be due in part to the presence of ballast or bedding material around the outfall.

The sorting coefficient reflects the range of grain sizes in a sample and is calculated as the standard deviation (SD) in phi size units (see Table 4.1). In general, sediments composed of particles of similar size with a SD ≤ 0.5 phi are considered to be well-sorted and indicative of areas subject to fast moving currents or large disturbances (Folk 1968). In contrast, samples with particles of varied sizes with a SD ≥ 1.0 phi are characteristic of poorly sorted sediments. Most stations sampled in the Point Loma region in 2009 had poorly sorted sediments with sorting coefficients ranging from a low of 1.3 phi in January to a high of 1.9 phi in July (Appendix C.3). These results are typical of mid-shelf habitats and reflect the multiple origins of sediments in the region (see Emery 1960). This also suggests that these sites are not subject to fast moving currents or large physical disturbances. The main exception to this pattern occurred at station E14 in July, where sediments were moderately well sorted (i.e., SD = 0.7), and there was a higher percentage of coarse materials (8%) than at most other sites (see Appendix C.3). Visual observations of the sediments collected with this grab sample indicated the presence of coarse black sand and rocks, possibly related to ballast and bedding material for the outfall.

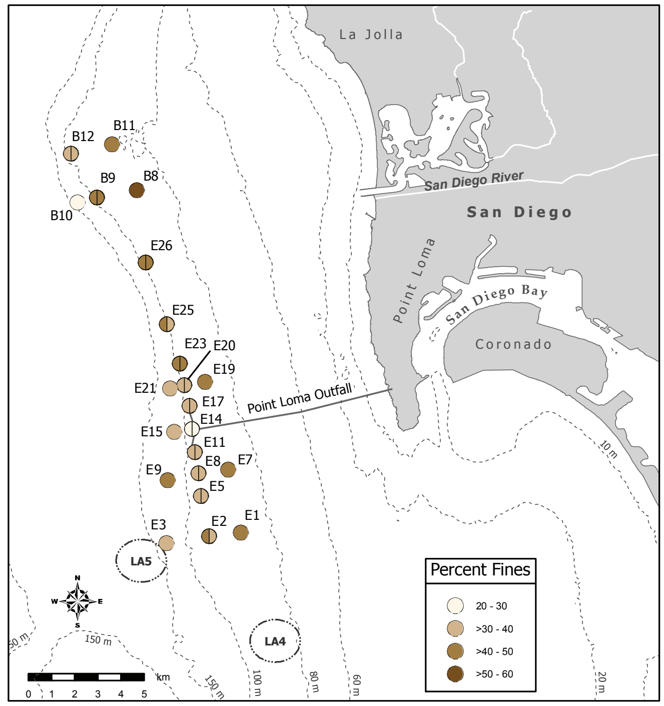

Figure 4.2
Distribution of fine sediments (percent fines) at PLOO benthic stations sampled during 2009. Only primary core stations were sampled in January; all stations were sampled in July (see text); split circles show results of January (left) and July (right) surveys.

Indicators of Organic Loading

Total organic carbon (TOC), total nitrogen (TN), total volatile solids (TVS), biochemical oxygen demand (BOD), and sulfides were quantified in sediments at the PLOO stations as potential measures of organic loading. The distribution of organic indicators in the region during 2009 was generally similar to that seen prior to wastewater discharge (see City of San Diego 1995). TOC, TN and TVS were detected in 100% of sediment samples, while BOD occurred in 97% of the samples (Table 4.1). Sulfides were also detected about 97% of the time, although results for the January samples from stations B9 and B12 were not reportable as they exceeded holding time limits. The highest concentrations of most organic indicators tended to occur at stations north of the outfall, including the reference "B" stations located almost 10 km or more from the end of the northern diffuser leg (see Appendix C.4). The main

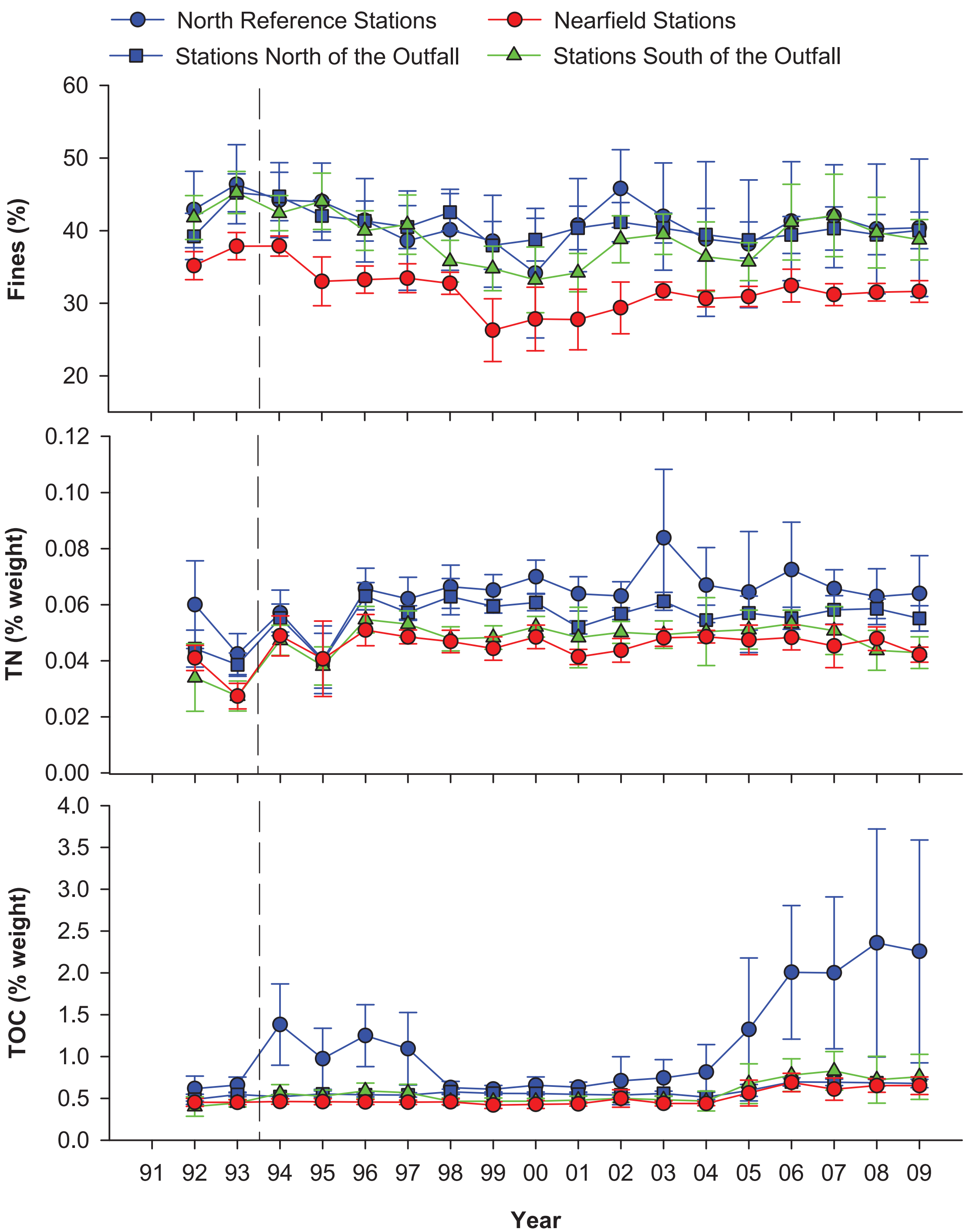

Figure 4.3

Summary of particle size and organic indicator data surrounding the PLOO from 1991–2009: Percent fines (Fines); Total Nitrogen (TN); Total Organic Carbon (TOC); Sulfides; Biochemical Oxygen Demand (BOD); Total Volatile Solids (TVS). Data are expressed as means pooled over all stations in each station group (North Reference = B8–B12; North of the Outfall = E19–E21, E23, E25, E26; Nearfield = E11, E14, E15, E17; South of the Outfall = E1–E3, E5, E7–E9); Error bars represent 95% confidence limits. Dashed lines indicate onset of discharge from the PLOO.

exceptions to this pattern were values for sulfides, which were highest at near-ZID station E14 during both surveys. In general, only sulfides, and to a lesser extent BOD, have shown changes near the outfall that appear to be associated with organic enrichment (see Figure 4.3; see City of San Diego 2007). Lastly, there was no correlation between sediment concentrations of organic indicators with the proportion of fine material within a sample ($r_s < 0.55$).

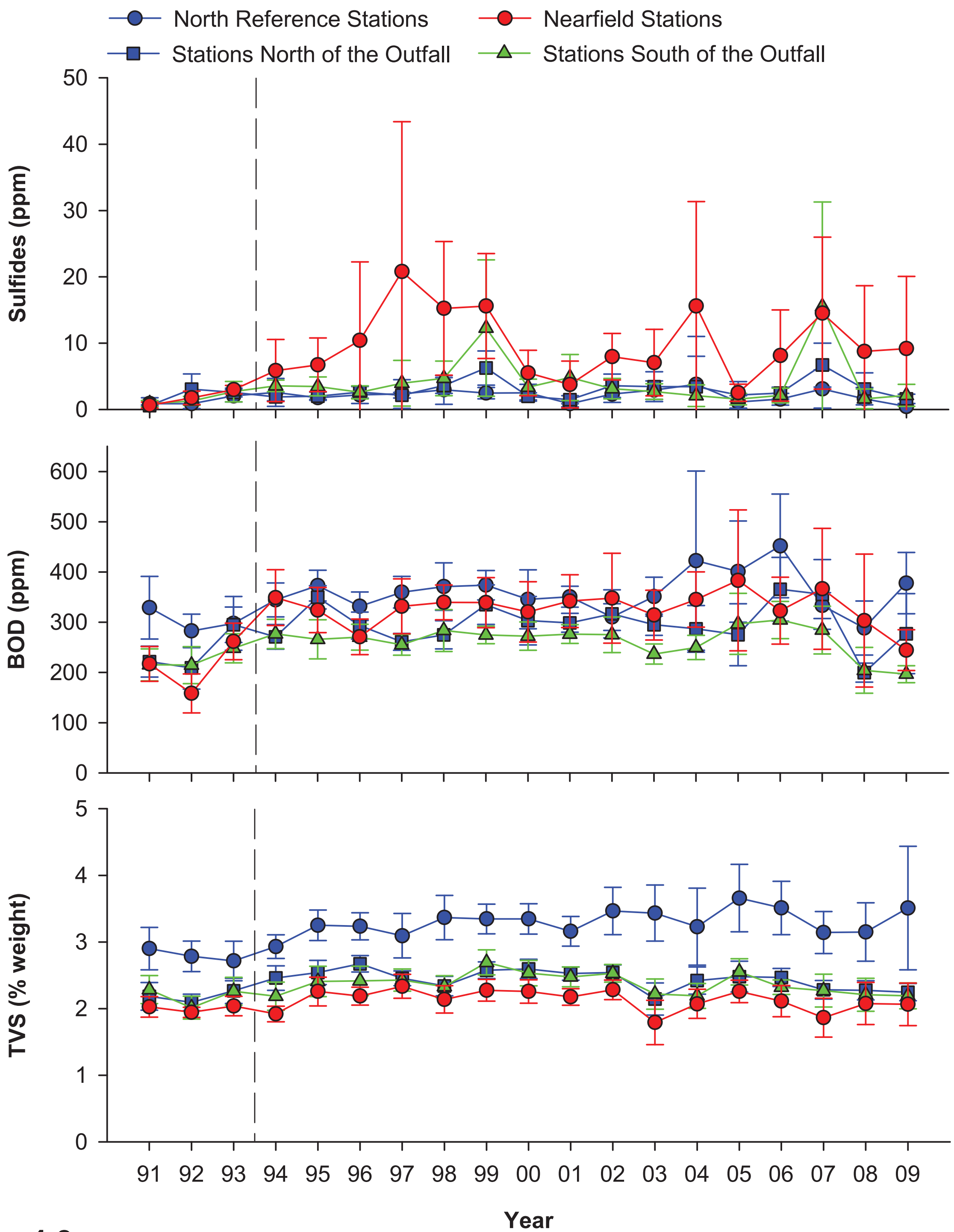

Figure 4.3 *continued*

Trace Metals

Detectable levels of aluminum, arsenic, barium, chromium, copper, iron, lead, manganese, mercury, nickel, and zinc occurred in all of the sediment samples collected in the Point Loma region during 2009 (Table 4.1). Another five metals (i.e., antimony, beryllium, cadmium, selenium, tin) were detected less frequently at rates of 6–94%, while silver and thallium were not detected at all. Metal concentrations were variable, and there were no discernable spatial patterns relative to the outfall. Instead, concentrations of four metals (i.e., barium, copper, manganese, nickel) were positively correlated with the proportion of fine

Table 4.2

Results of Spearman Rank correlation analyses of percent fine material with sediment chemistry parameters from PLOO benthic samples collected in 2009. Shown are analytes which had correlation coefficients (r_s) ≥ 0.60. For all analyses, $p < 0.001$. A representative correlation is illustrated graphically in Figure 4.4 below.

Analyte	r_s
Trace Metals (ppm)	
Barium	0.69
Copper	0.60
Manganese	0.66
Nickel	0.68

particles in the sample (Table 4.2, Figure 4.4). In addition, the highest metal concentrations tended to occur in sediments from the north reference stations and/or stations located south of the outfall. For example, the highest concentrations of arsenic, beryllium, cadmium, chromium, and iron were detected in sediments collected from station B12 located farthest to the north (Appendix C.5). In contrast, the highest concentration of lead (13.2 ppm) occurred in sediments collected at station E14 in January. Overall, concentrations of the different trace metals were generally low in the region, with most values reported for 2009 being below the highest concentrations detected prior to wastewater discharge (e.g., see Appendix C.5). Finally, no samples collected during the year had metal concentrations that exceeded either the ERL or ERM sediment quality guidelines.

Pesticides

Chlorinated pesticides were detected in up to 71% of the samples collected from PLOO stations in 2009 (Table 4.1). Total DDT (primarily p,p-DDE) was the most prevalent pesticide, occurring in sediments from all but one station with an overall mean concentration of 507 ppt. Concentrations of this pesticide ranged from a low of 150 ppt to a high of 1120 ppt, the latter of which is still below both the ERL (1580 ppt) and maximum pre-discharge value (8800 ppt) for DDT (Appendix C.6). Another pesticide, hexachlorobenzene (HCB), was detected in 32% of the sediment samples at concentrations ranging from 67 to 1600 ppt. HCB occurred at two of the northern reference stations during January and at nine other sites throughout the region in July, the latter including nearfield station E11. The maximum concentration of HCB was detected at station E2, located east of the LA-5 disposal site about 4 km south of the outfall. Two other types of pesticides, chlordanes and endrin aldehyde, were detected for the first time in PLOO sediments since monitoring began, which may be due to recent improvements in analytical techniques for such compounds. However, these two pesticides were detected in low

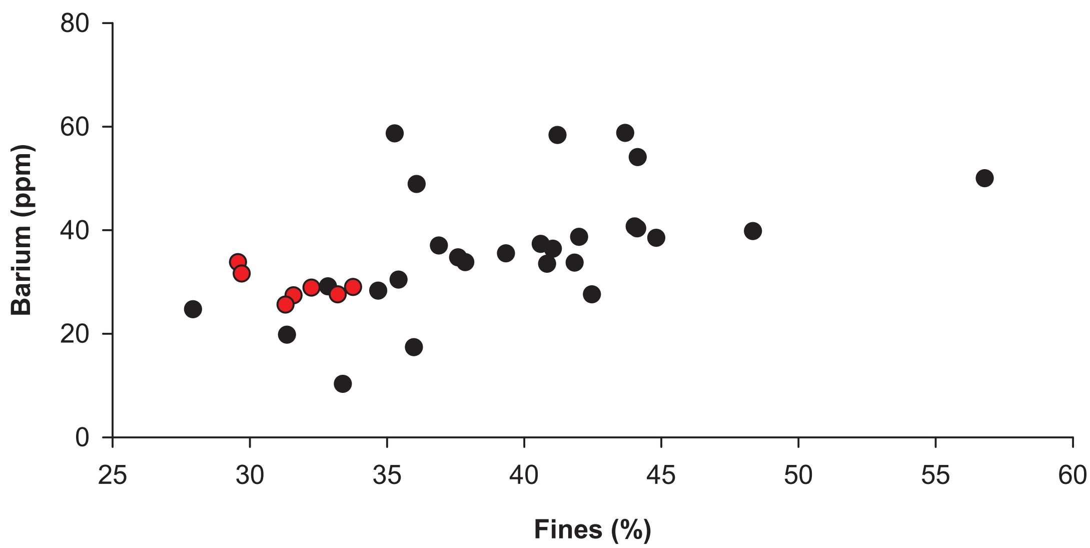

Figure 4.4

Scatterplot of percent fines and concentration of barium in PLOO sediments in 2009. Samples collected from nearfield stations are indicated in red.

concentrations (i.e., near or below the MDL) in a total of only three samples during the July survey. Chlordanes were detected in two sediment samples from stations E1 and E3 located adjacent to or east of the LA-5 disposal site, while endrin aldehyde was detected in a single sample from station E8 located just over 1 km south of the PLOO discharge area. As with the organic indicators and most metals, pesticide concentrations were unrelated to the fine fraction of sediments in a sample ($r_s < 0.44$), and there were no patterns indicative of an outfall effect.

PCBs and PAHs

Polychlorinated biphenyl compounds (PCBs) were detected in 50% of all PLOO sediment samples during 2009 (Table 4.1), most of which were collected from stations south of the outfall (see Appendix C.6). Total PCB concentrations ranged from 71 to 22,315 ppt in the region, with the highest levels occurring at two sites located between the LA-5 disposal site and the mouth of San Diego Bay (i.e., stations E1 and E3), and from one site (station E9) located between LA-5 and the southern leg of the PLOO. Each of these stations also had the highest number of detected PCB congeners (e.g., up to 24/sample) (see Appendix C.2). PCBs have historically occurred at these and other stations located within 2–5 km of LA-5, possibly due to the presence of dredge material dumped short of the intended site (see City of San Diego 2007, Parnell et al. 2008). With the exception of the January sample from station E11, all other detections of PCBs in the region were substantially lower (e.g., < 1300 ppt), and there was no evidence of PCB enrichment surrounding the PLOO.

While PCBs were detected in sediments from several PLOO stations throughout 2009, PAHs occurred at only three sites (i.e., stations E2, E3 and E9) at a detection rate of 9% (Table 4.1). Total PAH concentrations ranged from 95 to 312 ppb (mean = 174 ppb), well below the ERL of 4022 ppb (Appendix C.6). The most prevalent PAHs were 3,4 benzo(B)fluoranthene, benzo[A]anthracene, and chrysene (Appendix C.2), which occurred at all three of the above stations. Overall, there was no apparent relationship between PAH concentrations and proximity to the outfall discharge site.

Summary and Conclusions

Ocean sediments at stations surrounding the PLOO in 2009 were comprised primarily of fine sands and coarse silt. Most of these sediments were poorly sorted, consisting of particles of varied sizes, which suggest that sediments in the region were subject to low wave and current activity and/or physical disturbance. The moderately well sorted sample collected at station E14 in July was an exception, consisting of mostly fine sands, with some coarser materials which may have originated as ballast or bedding material for the outfall structure. Overall, variability in the particle size composition of sediments in the PLOO region is likely affected by both anthropogenic and natural influences, including outfall construction materials, offshore disposal of dredged materials, multiple geological origins of different sediment types, and recent deposition of detrital materials (e.g., Emery 1960, City of San Diego 2007, Parnell et al. 2008). The PLOO lies within the Mission Bay littoral cell, with natural sources of sediments including outflows from Mission Bay and the San Diego River (Patsch and Griggs 2006), as well as from San Diego Bay. However, fine particles may also travel in suspension across littoral cell borders up and down the coast (Farnsworth and Warrick 2007), thus widening the range of potential sediment sources to the region.

Concentrations of various contaminants, including most indicators of organic loading (e.g., BOD, TN, TVS), trace metals, pesticides (e.g., DDT), PCBs, and PAHs in sediments off Point Loma remained within the typical range observed for San Diego and other areas of the southern California continental shelf (see Schiff and Gossett 1998, Noblet et al. 2003, Schiff et al. 2006). Low concentrations of chlordanes and endrin aldehyde were detected in PLOO sediments for the first time since monitoring began, although these pesticides occurred in only three samples from stations located south of the outfall. Likewise, PAHs were only rarely detected (i.e., 9% of samples). Although DDT was present in sediments at most stations, all concentrations were below thresholds of biological concern. Overall, there were no contaminants that exceeded the ERL or ERM thresholds in PLOO sediments in 2009.

There were no clear spatial patterns in sediment contaminants relative to the PLOO discharge site in 2009, with the exception of slightly elevated sulfide and BOD levels near the outfall as described in previous years (e.g., City of San Diego 2007). Instead, the highest concentrations of several organic indicators, metals, pesticides, PCBs, and PAHs were found in sediments from both the southern and/or northern-most stations. Historically, concentrations of contaminants have been higher in sediments at most of the southern stations (i.e., E1–E3, E5, E7–E9) than elsewhere off San Diego, which may be due in part to short dumps of dredged materials originally destined for LA-5 (see Anderson et al. 1993, City of San Diego 2003, Steinberger et al. 2003, Parnell et al. 2008).

Overall, there is little evidence of contaminant loading or organic enrichment in sediments throughout the PLOO region after 16 years of wastewater discharge. For example, concentrations of most measured parameters continue to occur at levels within the range of variability typical for the San Diego region (e.g., see City of San Diego 2007). The only sustained effects have been restricted to a few sites located within about 300 m of the outfall discharge site (i.e., stations E11, E14 and E17). These effects include a minor increase in sediment particle size through time, measurable increases in sulfide concentrations, and smaller increases in BOD (City of San Diego 2007). However, the data do not suggest that wastewater discharge is affecting the quality of benthic sediments to the point that it will degrade the resident marine biota in the PLOO region (e.g., see Chapters 5 and 6).

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